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Piezo-Electric pressure gauge by differential comparison with vacuum

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Abstract
The paper deals with a concept of piezoelectricity wherein extremely low pressures can be measured with use of piezoelectricity. Now all must be wondering what is so different about what we told. Here is it, when it comes to measuring higher pressures we have numerous instruments but when we have to measure very slight pressure difference, below the atmospheric pressure we have very limited gauges. Here is where we introduce our concept wherein you can measure very slight pressure variations by creating a pressure difference along the surface of the piezoelectric material.

Keywords: piezo electricity, pressure measurement, pressure difference, pressure gauge, differential comparison

1. Introduction
In the field of metrology one of the most common, widely used and influential term is the word called ―precise‖ or ―precision‖. When it comes to this crucial term of metrology, it means there is no surrogate value in terms of numbers while measuring a parameter i.e., there is no approximation of values. This is one of the challenges in metrology. So, we make use of the piezo technology for this purpose. What we are going to do here is - pressure measurement differentially, simply by just creating a pressure difference by obtaining extreme vacuum.

2. Piezoelectricity
The piezoelectric effect can be seen only in non-conductive materials. Piezoelectric materials can be classified mainly into two categories: crystals and ceramics. Quartz (SiO2) is a very good example for piezoelectric material. [1] Piezoelectricity otherwise known as piezoelectric effect can be defined as the generation of electricity when subjected to some mechanical stresses or vibrations. The word piezoelectricity simply means electricity resulting from pressure. The phenomenon called Piezoelectricity was discovered in the year 1880 by French physicists Jacques and Pierre Curie. [4] The piezoelectric effect is comprehended as the undeviating electromechanical intercommunication between mechanical and electrical state in crystalline materials having no conversion symmetry. [5] The piezoelectric effect is a reversible process shown in materials demonstrating the direct piezoelectric effect (the internal generation of electrical charge as a result of an exerted mechanical force). The materials that possess direct piezoelectric effect also illustrate reverse piezoelectric effect (the internal generation of a mechanical strain as a result of an exerted electrical force). For instance, lead zirconate titanate crystals will produce quantifiable piezoelectricity, when their static structure is deformed by about 0.1% of the primitive dimension. Inversely, those same crystals will change about 0.1% of their changeless dimension when an external electric force is exerted on the material. The inverse piezoelectric effect is utilized in the creation of ultrasonic sound waves. [6] Piezoelectricity has wide variety of applications and some of them are listed below.

- The production and detection of sound
- Generation of high voltages
- Electronic frequency generation
- Used in microbalances
- To drive an ultrasonic nozzle
- In ultrafine focusing of optical assemblies
- Used in scientific instrumental techniques with atomic resolution
- Used in scanning probe microscopes such as STM, AFM, MTA, SNOM, etc.
- Used as ignition source for cigarette lighters
- Used in push-start propane barbecues. [7]

The features of the piezoelectric effect are closely related to the development of electric dipole moments in solid materials. The latter may either be activated for ions on crystal lattice sites with asymmetric charge surroundings (as in BaTiO3 and PZTs) or may directly be transported by molecular groups (as in cane sugar). The dipole density or polarization (dimensionality [Cm/m3]) can be easily estimated for crystals by summing up the dipole moments per volume of the crystallographic unit cell. [8] The dipole density P is a vector field as every dipole is a vector. Dipoles near each other are likely to get lined up in regions called Weiss domains. The domains usually get aligned randomly, but it can also be oriented using the process of poling (not the same as magnetic poling), a process by which a strong electric field is exerted on a material, usually at exalted temperatures. All piezoelectric materials cannot be poled. [9] Of resolute significance for the piezoelectric effect is the change of polarization P when exerting a mechanical pressure. This might either be happened by a re-configuration of the dipole-inducing or by re- alignment of molecular dipole moments under the effect of the extraneous tension. Piezoelectricity may then display a variation of the polarization strength, its direction or both, with the details depending on

- The alignment of P within the crystal
- Crystal symmetry
- The applied mechanical stress.

The change in P becomes noticeable as a variation of surface charge density upon the crystal faces, i.e. as a change in the electric field continues between the faces created by a change in dipole density in the major part. For example, a 1 cm cube of quartz with 2 KN (500 lbf) of precisely applied force can generate a voltage of 12500 V. [10] Piezoelectric substances also exhibit the opposite effect, called converse piezoelectric effect, where the exertion of an electrical field causes mechanical deformation in the crystal. [11]

3. Pressure

Pressure (symbol: p or P) can be defined as the ratio of force to the area over which that force is spread out. Pressure is force per unit area applied in a direction perpendicular to the surface region of a material. Gauge pressure can be defined as the pressure compared to the local ambient pressure. Pressure can be measured in any unit of force divided by any unit of area. The unit of pressure in SI is newton per square metre, which is called the Pascal (Pa) after the seventeenth-century philosopher and scientist Blaise Pascal. In US/UK customary units, the unit of pressure is lbf/square inch (PSI). A pressure of 1 Pa roughly equals the pressure applied by a dollar bill lying flat on a table. Everyday pressures are commonly expressed in kilopascals (1 kPa = 1000 Pa) – 1 kPa is approximately one-seventh of a lbf/in2. [12] Atmospheric pressure can be defined as the force per unit area applied on a surface by the weight of air above that surface in the atmosphere of Earth (or that of another planet). In most of the situations atmospheric pressure is firmly proximate by the hydrostatic pressure induced by the weight of air above the computation point. On a given plane, low-pressure regions have less atmospheric mass above their location, whereas high-pressure regions have more atmospheric mass above their location. Similarly, as altitude increases, overlying atmospheric mass becomes less so that with increasing altitudes atmospheric pressure decreases. On a moderate scale, a column of air one square centimeter in cross-section, calculated from sea level upto the top of the atmosphere, possess a mass of approximately 1.03 kg and weight of approximately 10.1 N (2.28 lbf) (A column one square inch in cross-section would have a weight of about 14.7 lbs., or about 65.4 N). [13]

4. Pressure Gauges

There are so many approaches developed for the computation of vacuum and pressure. Pressure gauges or vacuum gauges are the instruments developed for pressure measurement. A 'manometer' is an instrument that utilizes a column of liquid to compute pressure, despite the word is commonly used in the present scenario to refer to any pressure measurement device. A vacuum gauge is a device used for measuring the pressure in vacuum— which is further classified into two sub categories, high and low vacuum (and sometimes ultra-high vacuum). The relevant pressure fields of many of the methods used to measure vacuum is having an overlap. Hence, by integrating various types of gauge, it is desirable to compute pressure of the system continuously from

10 mbar down to 10−11 mbar. [14] Static pressure is homogeneous in all directions, so pressure measurements are not affected by direction in an immobile (static) fluid. However, flow exerts further pressure on surfaces perpendicular to the direction of flow, while possessing little influence on surfaces parallel to the flow direction. This directional element of pressure in a mobile (dynamic) fluid is called dynamic pressure. An apparatus facing the flow direction calculates the sum of the static and dynamic pressures; this measurement is referred to as the total pressure or stagnation pressure. Since dynamic pressure is attributed to static pressure, it is neither gauge nor absolute; it is obviously a differential pressure. While static gauge pressure plays the role of deciding net loads on pipe walls, dynamic pressure is used for measurement of flow rates and speed of air. It is possible to compute dynamic pressure by taking the differential pressure between devices parallel and perpendicular to the direction of flow. For example pitot-static tubes, carry out this measurement on airplanes to determine air speed. The presence of the measuring instrument undoubtedly serves to redirect flow and generate turbulence, so its shape is detracting to accuracy and the calibration curves are often non-linear. [14]

5. Loading under Pressure

Two methods, namely the air-tight sheet method and the vacuum-drain method (sheet-less), are generally used to conduct vacuum consolidation in the field. The advantages and disadvantages of both methods and the techniques for preventing vacuum leakage through a middle sand layer in a deposit, as well as the method for maintaining vacuum pressure when large settlement occurs. Vacuum pressure is an isotropic consolidation pressure applied to a soil deposit, and the deformation induced is different from that induced by a surcharge (e.g. the weight of an embankment). Two typical case histories in Japan are presented and deformation analyses were conducted. In one case history the vacuum-drain method was used with vacuum pressure alone, and in the other a combination of embankment loading and vacuum pressure was applied employing the air-tight sheet method. It is shown that under vacuum pressure loading, the ground deformation (settlement and lateral displacement) can be calculated reliably using a method proposed previously. For the case involving a combination of vacuum pressure and embankment load, the settlements under the embankment centre line can be estimated reasonably assuming one-dimensional deformation conditions. [15]

6. The Concept

The setup consists of an air tight box with two segments namely, one closed air tight segment connected to a vacuum pump whose vacuum pressure can be adjusted and the other segment filled with the fluid whose pressure is to be measured or left open in the case when the pressure of the surrounding atmosphere is to be measured. Most importantly a piezoelectric ceramic or crystal (preferably quartz crystal as it is second most abundant mineral available in nature). Inside the box, the crystal is placed in such a manner that the crystal's one half is in the segment that is filled with the fluid to be measured and the other half is in the segment which is in extreme vacuum pressure. This piezoelectric crystal is connected to a transducer that is capable of tapping the energy from the piezoelectric crystal or ceramic. Later this electric potential is measured as the pressure by use of a mechatronic system. The working is as simple as the setup looks. But initially before measuring the pressure of any fluid the so called pressure gauge has to be calibrated. This is how it should be done, the room temperature must be fed into the mechatronic system and then the vacuum pressure should be set and the vacuum suction should be done. Now the pressure difference on the piezoelectric crystal will produce a potential and a current is generated. This value of current must be reset to zero after making sure the vacuum pressure is constant. Now the fluid should be let into the second segment whose pressure is now shown in the display after getting processed in the mechatronic system.

7. Calculation

$D = \varepsilon E \quad => D_i = \varepsilon_{ij}E_j$............................ (1) [16]

Where, D is the electric charge density displacement (electric displacement), ε is permittivity and E is electric field strength, and Hooke's Law:

$S = st \quad => S_{ij} = s_{ijkl}T_{kl}$........................... (2) [16]

Where, S is strain, s is compliance and T is stress.

We also know that,

Increase in ΔP α increase in P

(Of the piezoelectric crystal) (Of fluid)

i.e., increase in pressure difference on the piezoelectric crystal is directly proportional to the increase in pressure of the fluid measured.

Where, ΔP – difference in pressure of the two halves of the piezoelectric crystal.

8. TABLE

Table 1: List of Piezoelectric Materials

Sl. No.	Major varieties of Quartz crystal	
1.	Chalcedony	
2.	Agate	
3.	Onyx	
4.	Jasper	
5.	Aventurine	
6.	Tiger's eye	
7.	Rock crystal	
8.	Amethyst	
9.	Citrine	
10.	Prasiolite	
11.	Rose quartz	
12.	Rutilated quartz	
13.	Milky quartz	
14.	Smoky quartz	
15.	Carnelian	
16.	Dumortierite quartz	[16]

9. Diagrams

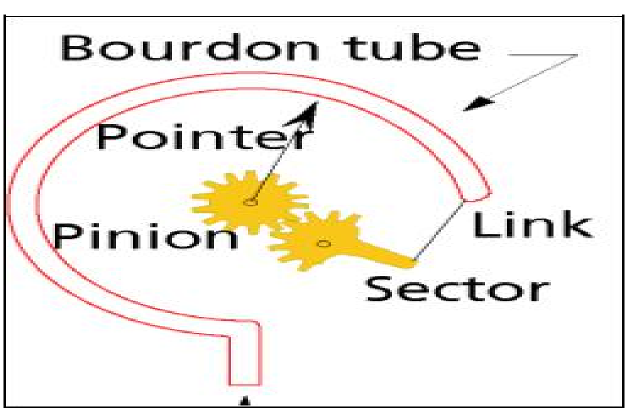

Fig 1: A Simple Mechanical Pressure Gauge [17]

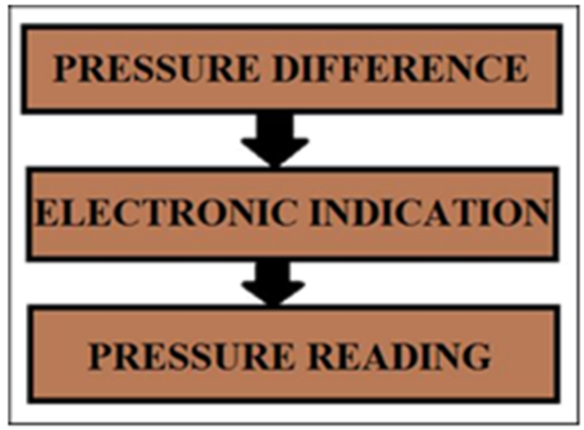

Fig 2: Schematic Flow Chart of the Working of the Gauge

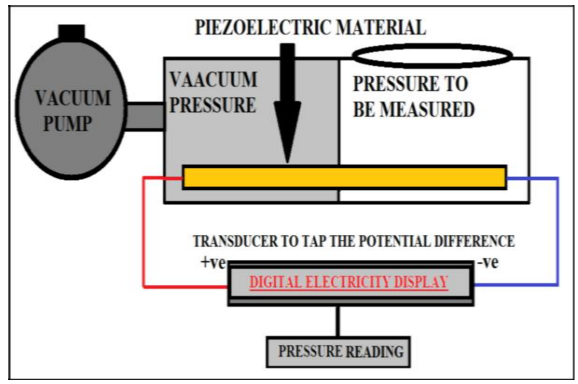

Fig 3: The Setup of the Gauge

10. Definitions

Ceramic

A ceramic is an inorganic, nonmetallic solid developed by the operation of heating followed by cooling Ceramic substances may possess a crystalline or partly crystalline structure, or may be amorphous (e.g., a glass). Since

Most common ceramic materials are crystalline, the definition of ceramic is usually confined to inorganic crystalline materials, contradictory to the non-crystalline glasses, a contrast followed here. [18]

Crystal

A crystal or crystalline solid is a solid material whose constituents, such as atoms, molecules or ions, are organized in a highly arranged microscopic structure, forming a crystal lattice that ranges in all directions. Additionally, macroscopic single crystals are usually distinguishable by their geometrical shape, consisting of flat faces with specific, characteristic orientations and alignments. [19]

Quartz

Quartz is the second most ample mineral present in the Earth's continental crust, after feldspar. It is made up of a continuous framework of SiO_4 silicon– oxygen tetrahedral, with each oxygen being shared between two tetrahedral, giving an overall formula SiO_2. [20]

Strain

Deformation in continuum mechanic is the alteration of a body from a reference to a current. [21]

11. Merits of This Gauge

This gauge has a few remarkable significant merits, they are:

The gauge though a mechanical gauge works with a mechatronic system and hence attains perfection (A mechatronic system is more reliable than a merely mechanical system).

The system shows the changing pressure of the liquids as and when the properties change.

The calibration is what we set and not dependent on any factor. So, there are lesser chances of errors.

The accuracy of the system can be increased by increasing the units of the vacuum segments or chambers.

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